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METALLURGICAL CHANGES IN THE HIGH TEMPERATURE FRETTING OF Ni AND Ti ALLOYS

First Technical Report

By

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Summary

An experimental rig has been constructed for testing the fretting fatigue behaviour of two materials in use in gas turbines, viz. Ti-6Al-4V and Inconel 718. Initial tests on Ti-6Al-4V show that the fatigue life is reduced as the temperature is raised and this is associated with the development of a layer structure on the surface.

Introduction

Fretting corrosion occurs in practice where two metal surfaces in contact undergo oscillatory tangential motion. At room temperature debris is produced which consists largely of the expected oxide, although in the case of iron and steel the oxide is a high temperature oxide, namely αFe_2O_3. In many practical instances the relative movement is due to one of the members of the contact undergoing cyclic stress, i.e. fatigue. Under these circumstances fretting can drastically affect the fatigue strength, reducing it by a factor of 2 or 3 or even greater. All the evidence suggests that the initial damage to the two surfaces results from the rupture of existing oxide films followed by local welding and local high strain fatigue. The welded material is smeared over the surface and is subsequently removed as loose debris by a process of delamination. It is in the early stages of local welding that fatigue cracks are initiated. Further evidence from structural changes in the surfaces in the fretted region suggests that there is a local temperature rise associated with the fretting process and this could have a profound effect on the mechanical properties of a heat treated material, which is usually the case where creep resistant materials are concerned. The purpose of the present project is to investigate these changes in two alloys, Ti-6Al-4V and Inconel 718 and to propose improved treatments to combat fretting damage.

Little work has been published on the effects of temperature on fretting fatigue and so a further purpose of the investigation is to assess the role of the oxide film, of greater thickness and plasticity, on preventing the welding stage of fretting which is particularly associated with the initiation of fatigue failure.

Experimental

The first part of the programme is concerned with obtaining fretting-fatigue data on the two materials at elevated temperatures. The fatigue machine which is being used for this purpose is the Avery Midget Pulsator, a push-pull machine. The specimens are machined from 4.76 mm ($^3/16$ in.) diameter rod. The centre portion of the specimen has two parallel flats machined on it, reducing the thickness to 1.59 mm ($^1/16$ in.) over this section. The ends of the specimen are threaded to secure it in the chucks of the machine. Fretting is produced by clamping a pair of bridges, made from the same material as the specimen, on to the flats with a proving ring. The bridges are 19.05 mm ($\frac{3}{4}$ in.) long and 3.18 mm ($\frac{1}{8}$ in.) wide. The specimen is surrounded by a split furnace which has two resistance elements in each half of the furnace. The arrangement is shown diagrammatically in Fig. 1. Fig. 2 is a photograph of the furnace assembly with the top half removed, showing the specimen with the bridges clamped on to it by means of the proving ring. Fig. 3 is a general view of the fatigue machine and temperature controlling equipment. The proving ring is located outside the furnace but the prongs holding the bridges are within the furnace and therefore must be of a

creep resistant material, which in this case is Nimonic 90. Initially the two faces of the two halves of the furnace were made of stainless steel sheet. Careful temperature surveys in both longitudinal and radial directions revealed that at 600°C there was a variation of 34° over the gauge length of the specimen. Relocation of the heating elements and replacement of the stainless steel by sindanyo has reduced the temperature variation to within 3°.

Fretting-fatigue curves have been determined for specimens made from Ti-6Al-4V supplied by IMI under a mean stress of 248 MN/m^2 (16 tonf/in^2) and a clamping pressure of 31.8 MN/m^2 (2.06 tonf/in^2) at room temperature, 200°C and 600°C. The results are shown in Fig. 4.

A detailed examination of the damaged surfaces was made on the specimens tested at 200°C. At room temperature the fretting damage on Ti-6Al-4V is essentially of the delaminating type, showing removal of flat plates of material about 2 μ in thickness. At 200°C the damage was considerably different and showed the development of a layered structure as in Fig. 5. The multiple layers of material can be seen in the vicinity of the fracture, Fig. 6. The specimens tested at 600°C have yet to be examined in the scanning microscope.

Discussion

The major part of the effort so far has been devoted to ensuring that the experimental rig is satisfactory for testing the designated materials in fretting-fatigue at elevated temperatures.

The results to date show that the fretting fatigue life of specimens of Ti-6Al-4V progressively decreases as the temperature is raised. This seems to be associated with the development of a layered structure in the contact region which indicates that the fretting process is producing structural changes below the surface which appear to be having a greater effect than any change in the thickness and properties of the oxide film. Earlier work on mild steel showed that the increased thickness of the oxide film at temperatures above 140°C had a protective and lubricant effect thereby reducing the fretting damage. Early results suggest that this may be the case with the Inconel 718.

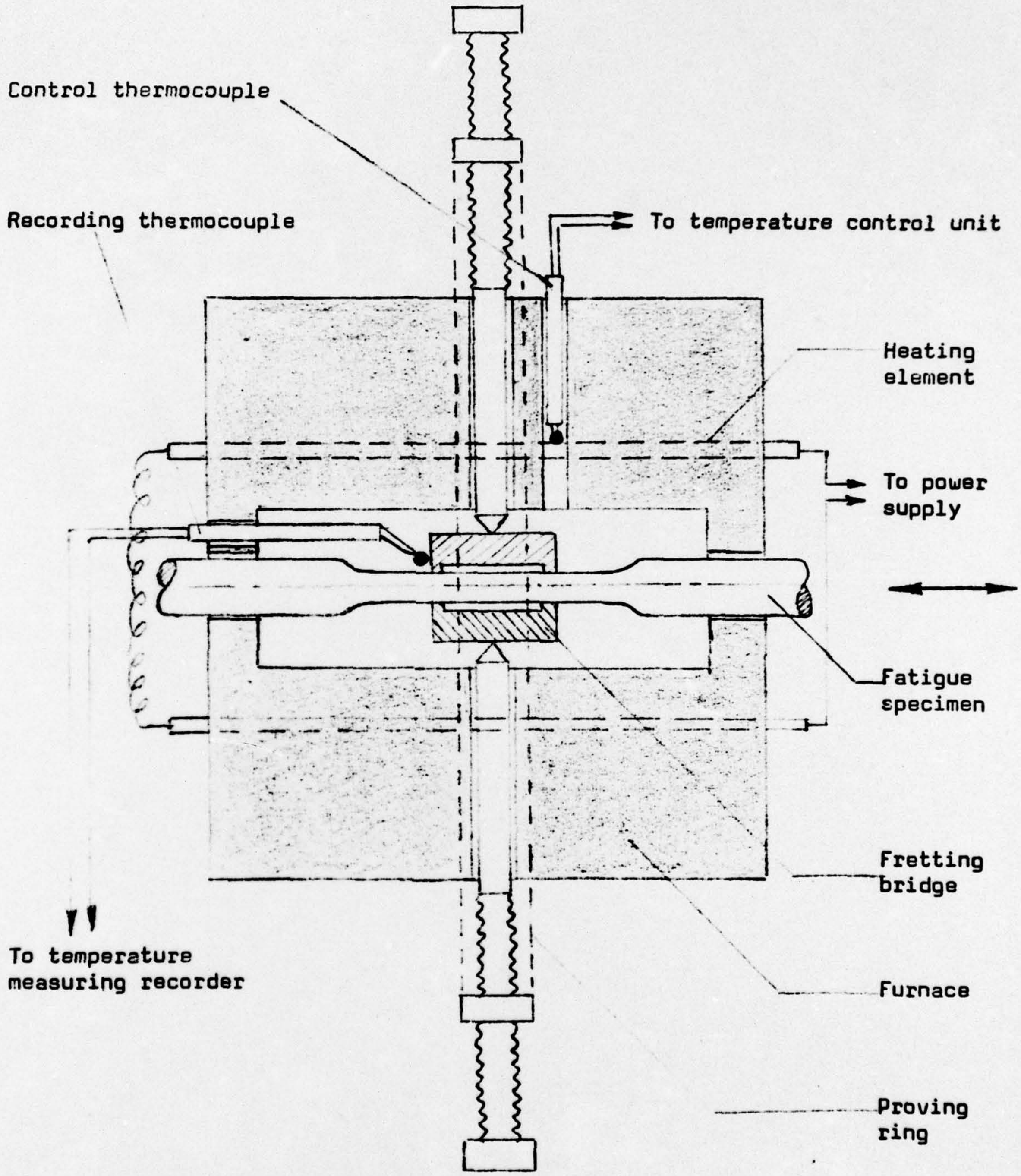


Fig. 1. Schematic drawing of the High-Temperature Fretting-Fatigue Test equipment.

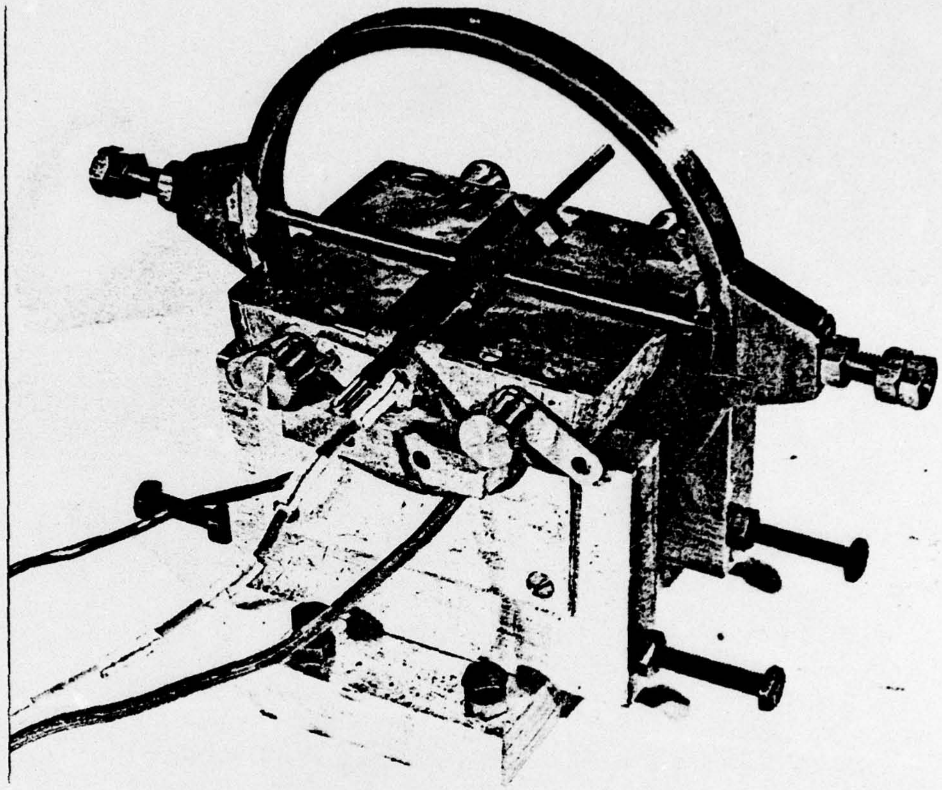


Fig. 2. End view of the test equipment showing the proving ring and bridges clamped to the specimen and the bottom half of the furnace.

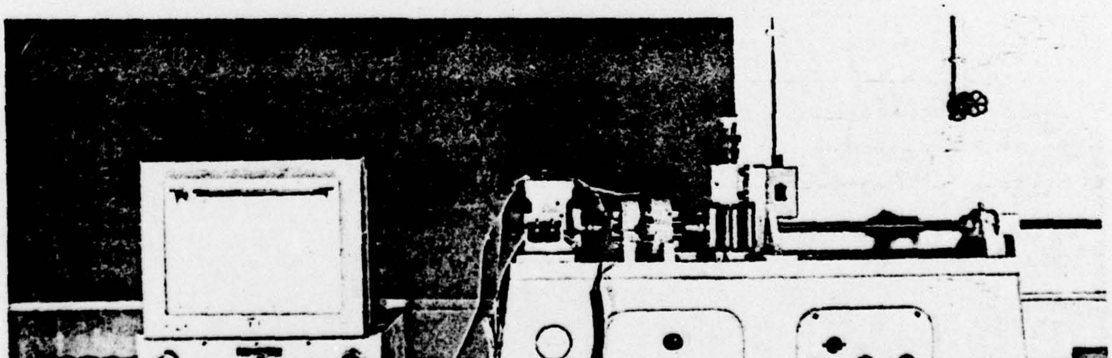
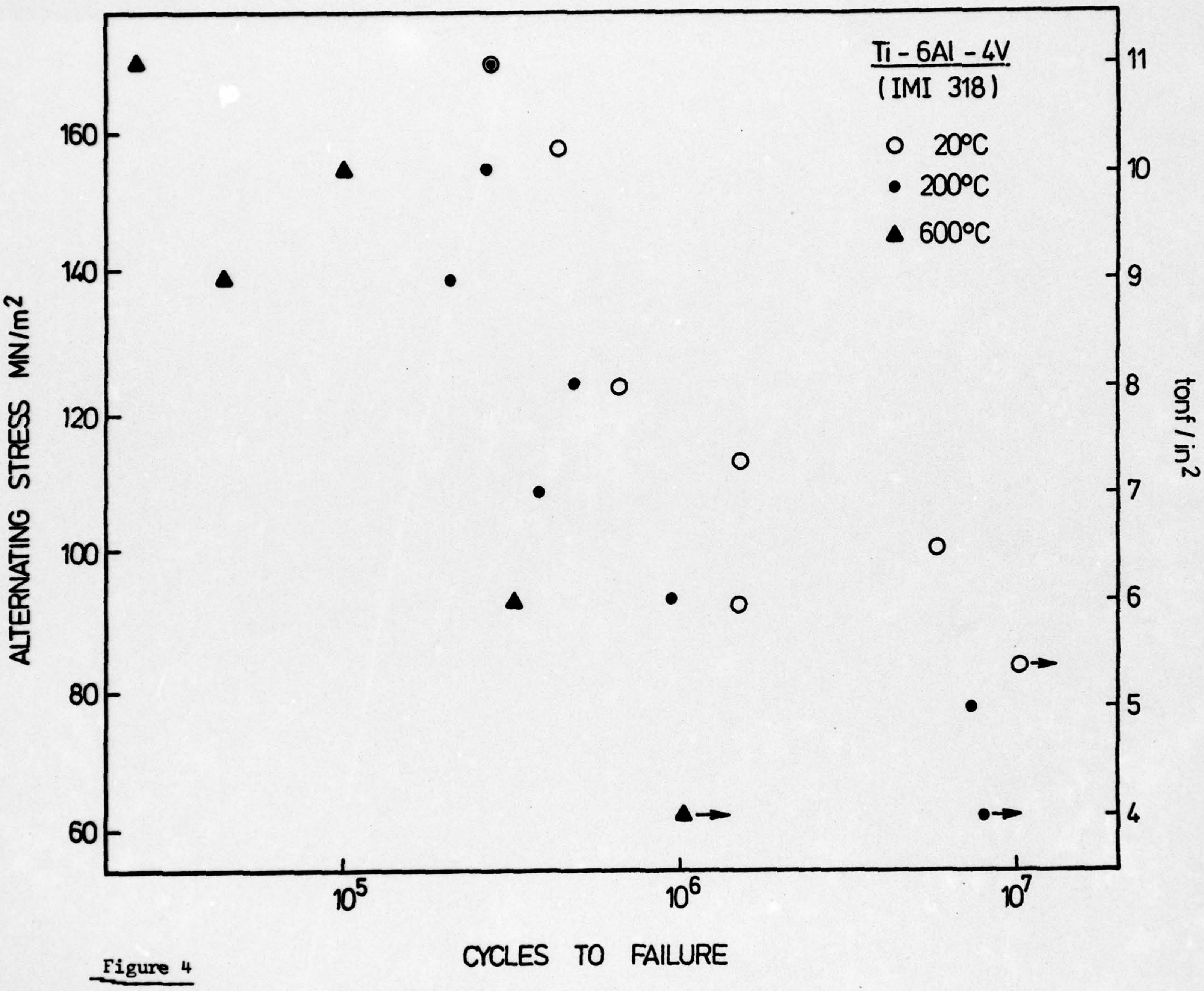


Fig. 3. Overall view of the test equipment, testing machine and control system.



Ti - 6Al - 4V
(IMI 318)
20°C
200°C
600°C
160
140
120
100
80
60
ALTERNATING STRESS MN/m2
11
10
9
8
7
6
5
4
tonf / in2
10^5
10^6
10^7
CYCLES TO FAILURE

Figure 4

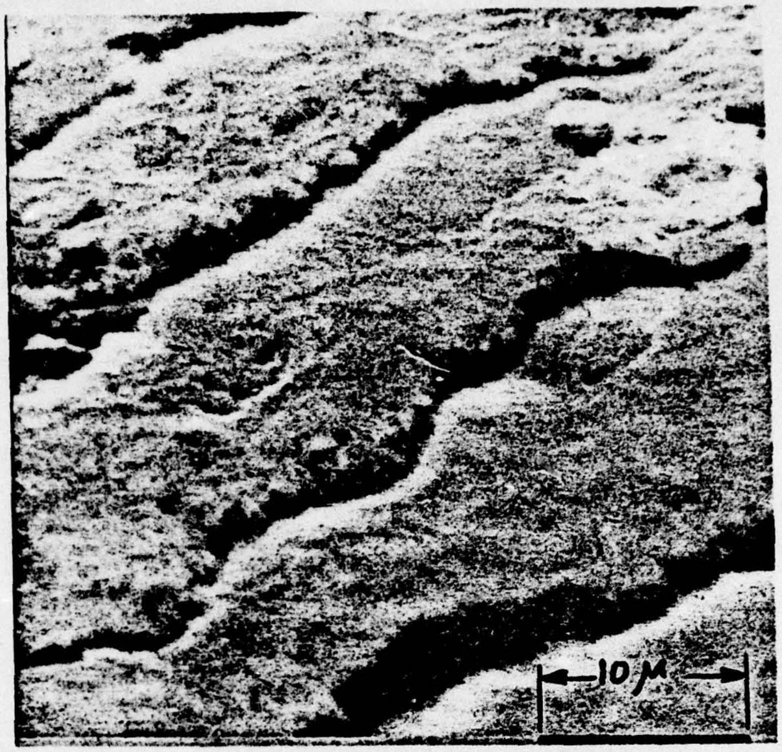


Fig. 5. Scanning electron micrograph of surface of Ti-6Al-4V (IMI 318) specimen tested at 200°C in air at a fatigue stress = 16 ± 9 tons/in^2.

Fig. 6. Scanning electron micrograph of surface of Ti-6Al-4V (IMI 318) specimen tested at 200°C in air at a fatigue stress = 16 ± 6 tons/in^2.

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